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APRIL-MAY, 1897

GLACIAL STUDIES IN GREENLAND. X.

The Bowdoin glacier.—The Bowdoin glacier is a lobe of the great inland ice-sheet which descends from the north into the head of the valley of Bowdoin Bay. It is joined on the east by ice pushing in through the intervals between a row of nunataks that lie on the plateau border. On the west it is confluent with the trunks of the Tuktoo and Sun glaciers which debouch into the broad flat valley at the head of McCormick Bay. This is only separated from the Bowdoin Bay valley by nunataks of which the Sierra and the Sentinel are the most conspicuous. These lie in the lower part of the common valley and have already been mentioned in connection with the Tuktoo glacier (see sketch map, p. 668, Vol. III). No very precise point can be fixed upon as the place of parting of the Bowdoin glacier from the main ice-cap, but it may fairly be regarded as having a length of six or eight miles. In its lower half it is joined on the east by the Obelisk glacier which comes in below the North nunatak and by the East Branch glacier which pushes in more directly from the east on the south side of the Obelisk nunatak. The East Branch glacier appears to terminate by lateral wastage almost at the point of joining the Bowdoin glacier and apparently never becomes really confluent with it. But the Obelisk glacier blends with and becomes a part of the Bowdoin glacier without being distinguished from it even by a medial moraine. The Bowdoin glacier in its lower part has a breadth of about two miles. It is the master glacier of the vicinity both in respect to dimensions and activity.

The descent of its floor is apparently between 2000 and 3000 feet. This is accomplished by a somewhat steep fall from the upland to the valley, and then by a notable but unequal decline throughout its remaining course. The inequality of the decline is indicated not only by the undulation of its profile, but by intensive crevassing which distinguishes it from most of the valley glaciers of the vicinity. The crevassed condition is well shown in Fig. 64 and is worthy of thoughtful consideration when the relatively slight undulations and the relatively slow movement of the glacier are taken into consideration. Such pro-

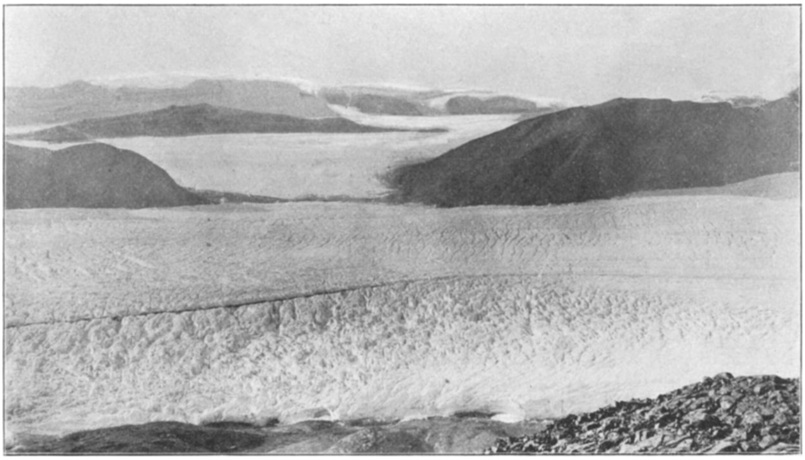

Fig. 64. Transverse view of Bowdoin glacier seen from the heights on the east looking northwesterly. The glacial movement is from right to left. The dark longitudinal line represents the sunken medial moraine. The undulations of the surface are fairly well indicated. The slope just beyond the crevassed area in the right foreground and between that area and the medial moraine inclines *backward, i. e.,* to the right, and a brook flows in that direction. The notable feature of the surface is the crevassing. The nunatak beyond the Bowdoin glacier on the right is the Sierra, that on the left the Sentinel. The Tuktoo glacier is seen between these and in the distance a glimpse of the Sun glacier is obtained. The ice-capped heights beyond are a part of the border of Prudhoe Land. Lieutenant Peary's first route across the icecap lay along these heights. Photograph by Professor Wm. Libbey, Jr.

nounced crevassing emphasizes the slight ductility of the ice. The failure of the ice to fill up the inequalities and form a continuously declining surface after the fashion of liquids is a further feature of interest. The undulations are so great as to give rise to irregular surface drainage. In one instance at least, to which I was guided by Lieutenant Peary, the drainage is reversed. A considerable brook runs in a direction *opposite* to that of the motion of the glacier. It flows northward while the glacier flows southward. The northward

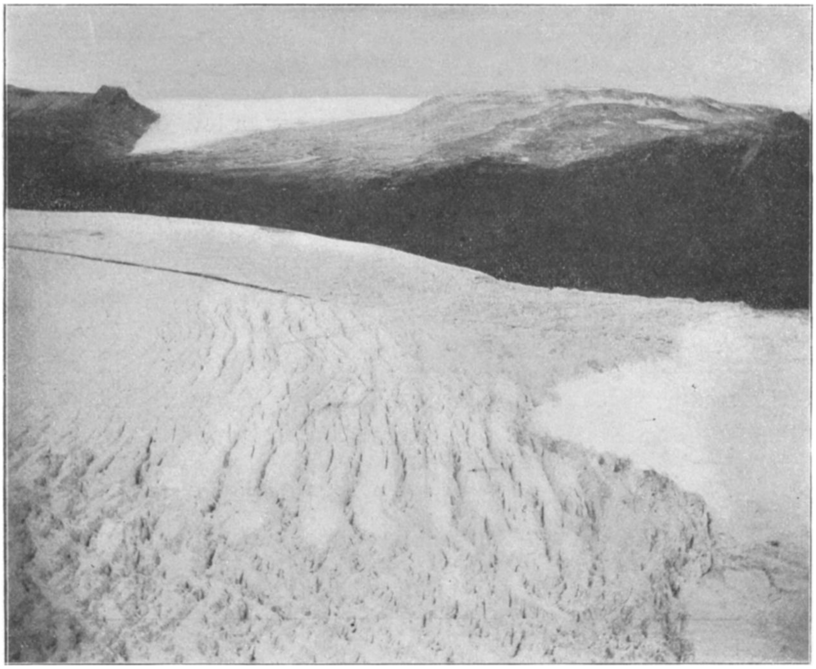

Fig. 65. The end of Bowdoin glacier. The head of Bowdoin Bay is seen at the right and the crevassed end of the glacier in the center and left. The dark line represents the medial moraine. The absence of other débris is notable. A portion of the ice-cap and the Mirror glacier are dimly seen in the distance. (The sky has been a little penciled.) The rounded embossment on the right is Bartlett Mountain, about 2600 feet high, the name being specifically applied to the frontal promontory. Sugar Loaf is seen at the left of Mirror glacier.

slope may be seen at the right hand of Fig. 64 a little this side of the medial moraine.

The Bowdoin glacier debouches at its lower extremity into the head of Bowdoin Bay and discharges icebergs of considerable dimensions, Fig. 65. This discharge seems to vary very greatly with the nature of the summer season. My observations happened to fall upon a season of relative quiescence. From the sixth to the twenty-third of August I occupied, through the kindness of Lieutenant Peary, a lodge overlooking the sea wall of the glacier and so near at hand as to be within easy hearing distance of any notable disruptive action but during this time I was not fortunate enough to witness the discharge of a single notable mass of ice, or even to hear it. A more substantial evidence of quiescence is found in the fact that within less than 200 yards of the extremity of the glacier on the east side there was an ice bridge spanning the lateral stream and connecting the glacier with a spur of rock. Lieutenant Peary informed me that the bridge had remained intact for two years and had been used as a means of communication with the glacier whose vertical face at other points rendered access difficult. It would be an error, however, to draw conclusions from these facts, for during the succeeding season the bridge was not only broken away but extensive discharges of icebergs took place along the sea face of the glacier. I presume that this unequal and somewhat spasmodic action represents the habit of the glacier. It seems probable that during a succession of severe seasons the motion of the ice is quite slight and the extremity of the glacier makes but little advance. But an exceptionally warm season following such a succession of severe ones, during which thickening and steepening of the gradient may have taken place, probably causes a notable thrusting forward of the glacial foot accompanied by corresponding iceberg discharge.

On its west side the Bowdoin glacier does not present an extensive vertical wall in accordance with the prevailing fashion of the region. In its upper part the glacier runs side by side with the trunk of the Tuktoo glacier, as already observed. Below this it rubs hard against the Sierra and Sentinel nunataks and its activity is such as to prevent the development of the fossæ which often lie between nunataks and adjacent glaciers. Between the two nunataks named the glacier protrudes westward to meet the reciprocal eastward protuberance of the Tuktoo glacier, and the two jointly impound two small triangular lakes in the angles between themselves and the nunataks. Where the protuberances are opposite to each other their extremities are not vertical, though steep and somewhat stepped. This is perhaps due to the absence of the reflecting frontal plane which I have thought might be one of the factors in the development of the vertical faces. Each glacier standing opposite to the other covers the ground which would otherwise act as a reflecting surface.

On the east side of the Bowdoin glacier, however, there is the usual vertical face with its accompanying sharp triangular valley between the ice and the adjacent rock slope. This extends from the extremity of the glacier to the point of its junction with the East Branch glacier, a distance of perhaps three miles. At a few points spurs of rock close the valley. East Branch hill projects notably into the path of the glacier and not only closes the lateral valley but crowds the border of the ice out of its path. At these points of interruption the stream, which as usual runs between the glacier and the valley side, is forced to tunnel under the glacier. After a cold day or two, the water in the stream becomes low and the tunnels then afford a means of penetrating to limited distances beneath the ice, Fig. 66. The phenomena so disclosed, however, do not essentially differ from those seen to better advantage in the vertical sides. The amount of débris appears more scant because it is not concentrated by surface melting nor exaggerated by surface wash. In some instances where blocks of ice had recently fallen away from the roof, opportunity was given for the study of exceptionally fresh unweathered ice which had not been subjected to the sun's rays, except as they reached it through considerable depths of ice. Even here the ice is far from being really compact and transparent. It varies from translucency in the more dense layers to nearly complete opacity in the more porous layers. This is an expression of lack of solidity and may be noted as specially instructive since the ice is here near

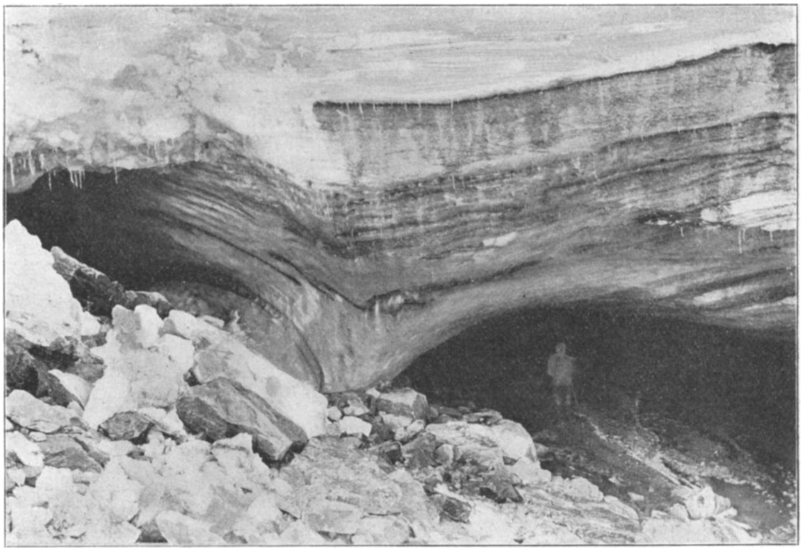

Fig. 66. Entrance to a tunnel under the side of Bowdoin glacier, looking downstream. The shoulder of rock which caused the undercutting of the stream is partially shown at the left. The peculiar arching of the beds is an interesting feature. Photograph by Professor Wm. Libbey, Jr.

the end of its career as a part of the glacier. As it was derived from the main ice-cap it may possibly have had as long a glacial history as often falls to such ice.

The stratification and the basal loading of the ice exhibited along the extended vertical face are much the same as in the glaciers previously described, but differ somewhat in the fact that the layers of ice are more warped and contorted, a result doubtless of the greater inequalities of the glacier's bed. Very notable dips of the glacial layers, both up stream and down stream, were frequently observed and sometimes reached large angles, in one instance 70°. These dipping planes were sometimes marked by débris (though more commonly not) showing that they were genuine planes of acquired stratification. But the distortion often went far beyond mere changes of dip, however great or abrupt. It amounted to crumpling and even to faulting. A special instance is illustrated in Fig. 67.

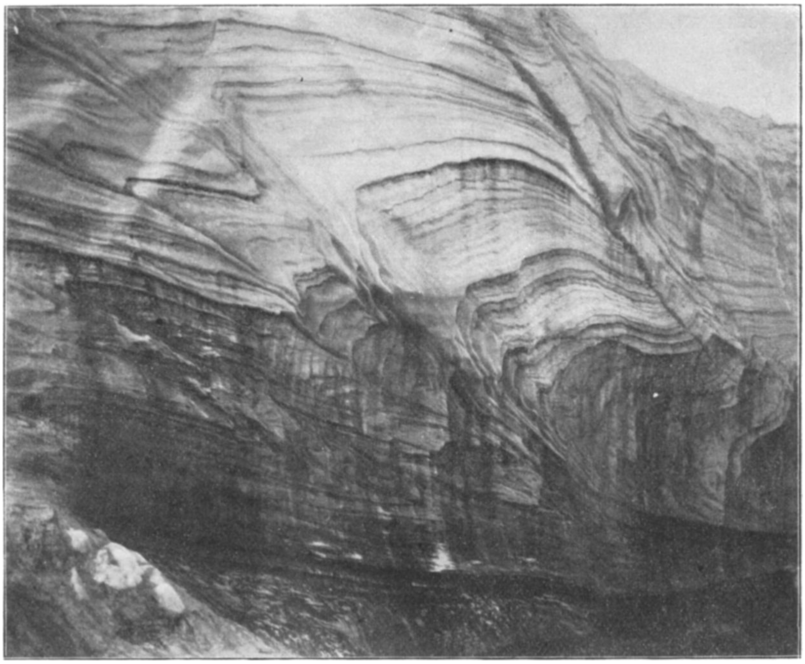

FIG. 67. Upthrusted and contorted ice layers on the east side of Bowdoin glacier just north of the East Branch hill. Lines of shearing, sharp flexures, localized belts of contortion and thrust, are among the notable features.

The débris does not rise so high in the Bowdoin glacier as in some of the others already described. This fact is perhaps worthy of special note as this is a tongue of the great ice cap and has descended over an undulatory bottom nearly to the sea level. It is perhaps further worthy of note because this glacier discharges into the sea. The basal layers are not forced upwards at their extremities to the same degree that was observed in some glaciers that have less free termination. A measurement of the upper limit of the débris-bearing layers at a point about two miles distant from the end of the glacier gave a height of only twenty-eight feet. Between this point and the extremity of the glacier the débris was usually confined to less heights, and at some points near the end it was not visible at all in the lateral face of the glacier. The amount of débris even within the limited range indicated was often relatively small and never very heavy. The accompanying photographs substantiate this. The bowlders of this glacier were usually more rounded than those previously described, and this rounding was of such a nature as to imply very considerable wear. The débris was composed wholly of crystalline rock, so far as observed, no admixture of clastic material being seen. The considerable rounding of the material, the small amount of débris and its low position at the base of the glacier are facts worthy of special note. They will be seen to have special significance when it is remembered that this is one of the larger (though not by any means the largest) tongues of the great ice-cap.

The rubbing of the glacier against shoulders of rock projecting from the side of the valley gave opportunity for observing some of the special phenomena of such situations. At one point the process of "plucking" was well indicated (though not actually observed) on the lee slope of a spur of gneissoid rock. Blocks ranging up to three or four feet in width and length and one or two feet in thickness had been detached in considerable numbers. The process involved much breaking and bruising with relatively little wear. Corners and angles were broken off and heavy bruise marks were observed both on the blocks and on the sides and edges of the cavities from which they had been removed. At some points considerable crushed rock was observed. On the other hand, systematic grooves and striæ were not abundant nor pronounced. The dynamic impression given was that of a forceful tearing out of blocks by the action of a relatively rigid agency which did not press the blocks hard upon the lee slope after their removal.

At the point where the glacier grinds against the projecting side of the East Branch hill, the ice was notably crevassed, the fractures being most open at the side and gradually closing as they passed away toward the axis of the glacier. They were directed obliquely up stream according to the general law of lateral crevasses. Immediately against the obstructing projection the ice was broken up into numerous blocks and fragments and somewhat piled up against the side of the hill or tumbled back upon the upper surface of the glacier. The same thing occurs on the opposite side where the glacier rubs hard against the Sierra nunatak.

Just north of the point of forceful contact with the East Branch hill, a very interesting instance of contortion and upward thrust was observed. The accompanying figure (67) shows the nature of this better than any verbal description. It may be observed that near the base there are two quite pronounced lines which have the appearance of special shear planes. The contortion of the central belt in being forced obliquely upward is well displayed in the photograph. While the cause of the phenomena cannot be positively stated, it associated itself in my mind with the obtrusion of the projecting point of East Branch hill immediately below it. Whether this be the cause or not, the phenomena impress me as a clear case of forceful localized thrust with resulting foliation and shear planes.

At the point where the East Branch glacier joins the Bowdoin glacier, a large amount of débris had accumulated from a medial moraine derived from the Obelisk nunatak lying between the East Branch and the Obelisk glacier. The accumulated rubbish was the terminal dump of the medial moraine. There appeared to be much ice beneath this accumulated débris. It was obvious that both it and the extremity of the East Branch glacier had become essentially stationary. The more active Bowdoin glacier (or the Obelisk glacier, for the two are continuous) had forced itself over the edge of this débris. The result was the bending upwards of the edges of the layers of the Bowdoin glacier. Accompanying this there was a phenomenon which seemed at the time to be a clear and unequivocal expression of the shearing of these layers over each other, due to the resistance of the morainic material. Subsequent studies, as elsewhere remarked, led to some skepticism as to the validity of this interpretation. This point was not visited after the skeptical spirit arose, and hence I am only able to reproduce the observations and interpretations as they impressed themselves at the time. On the nearly vertical face of the glacier where it was most strained in being thrust over the morainic mass, there were as many as nine distinct projections of upper layers over under layers. The over-projection was sharp and definite and at once attracted the notice of my companion, Mr. E. B. Baldwin, who called my attention to it. The ground for skepticism regarding the interpretation of phenomena of this class is the presence of débris bands which may give rise to differential melting. There is no question that projections of a kind much like those here observed are due to such unequal melting. It seems to be demonstrable also that overthrust shearing takes place in this way. Each case must therefore be judged by itself. The limited amount of débris in this glacier encourages less skepticism regarding overthrust here than in some other cases. My notes state that pebbles and bowlders were sometimes lodged between these layers and that they appeared to have been pushed along the face of the layers in the shearing process, sometimes making grooves in the ice. Both notes and memory imply scantiness of débris between the layers. Unfortunately my photographs at this point were not a success. The overjutting of the layers ranged from a few inches to eighteen inches. They were most pronounced where the strain resulting from the obstruction would naturally be greatest and they died away in either direction. At another point somewhat farther on the phenomenon was repeated, but here there were but five chief planes of displacement in the vertical section. The maximum displacement of two adjacent layers, however, exceeded two feet. The adjacent faces appeared to be very distinctly fluted by the movement. Skepticism with reference to the interpretation of the fluting was subsequently raised on the ground that it might perhaps be due to unequal melting by water trickling down the face of the ice, but, as elsewhere noted, in one instance at least, the débris in the junction plane was corrugated. It was noted here that a shearing plane was offset; that is, the shearing plane passed from the contact between two given planes to a similar contact between two planes below. The offset was downward and to the right or up-stream side. The overthrust was about six inches and the offsets, two of which were sketched, about eight inches.

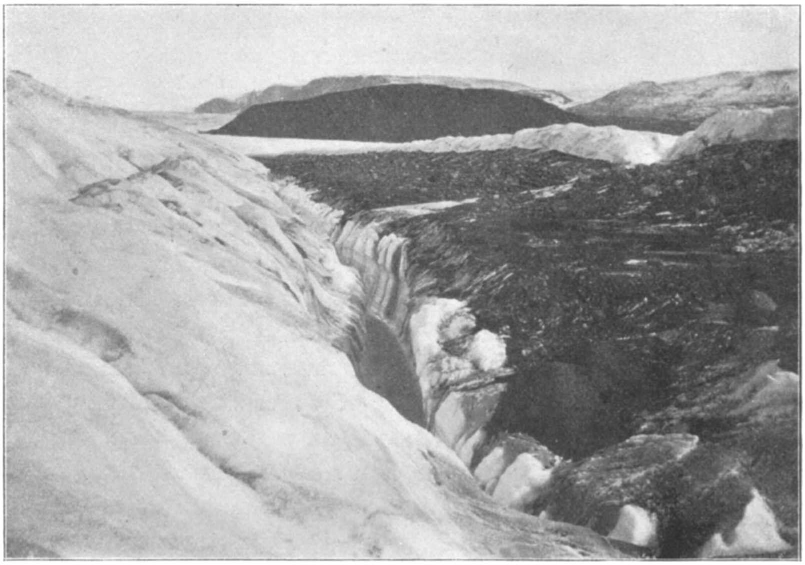

FIG. 68. Sunken medial moraine on the back of Bowdoin glacier; seen from a point near the moulin looking northerly. The ice motion is toward the foreground. The width of the moraine is about four rods and its depth below the general surface ten or fifteen feet. The stream's trench is shown at the left. It falls into the moulin at the lower right-hand corner. Glimpses of the main ice-cap are caught beyond the heights.

The back of Bowdoin glacier is marked by an interesting medial moraine that takes its rise far up toward its junction with the main ice-cap, Fig. 68. I did not see its origin, but Lieutenant Peary informed me that it came to the surface from beneath the ice at a point north of the north nunatak, but south of the descent of the ice from the main plateau. On account of this he could not be certain whether it was derived from a nunatak that lies still farther north on the border of the main plateau, or from some concealed embossment. Undoubtedly the material was picked up from a prominence on or near the edge of the plateau. The débris is so thinly spread that it catches the sunlight and by conversion and conduction makes its heat available to the ice. As a result the moraine is sunken ten or fifteen feet below the surrounding surface. In breadth and form it is not unlike a depressed street strewn with coarse débris. On one side of it a stream has cut a notable trench through which a considerable body of water flowed during the warm days of August. Fig. 68 illustrates the moraine and its depressed condition, as also the channel on the west side. The latter terminates in a moulin at the right-hand lower corner of the illustration. The moraine is also illustrated in the general transverse view of the glacier shown in Fig. 64.

T. C. CHAMBERLIN.